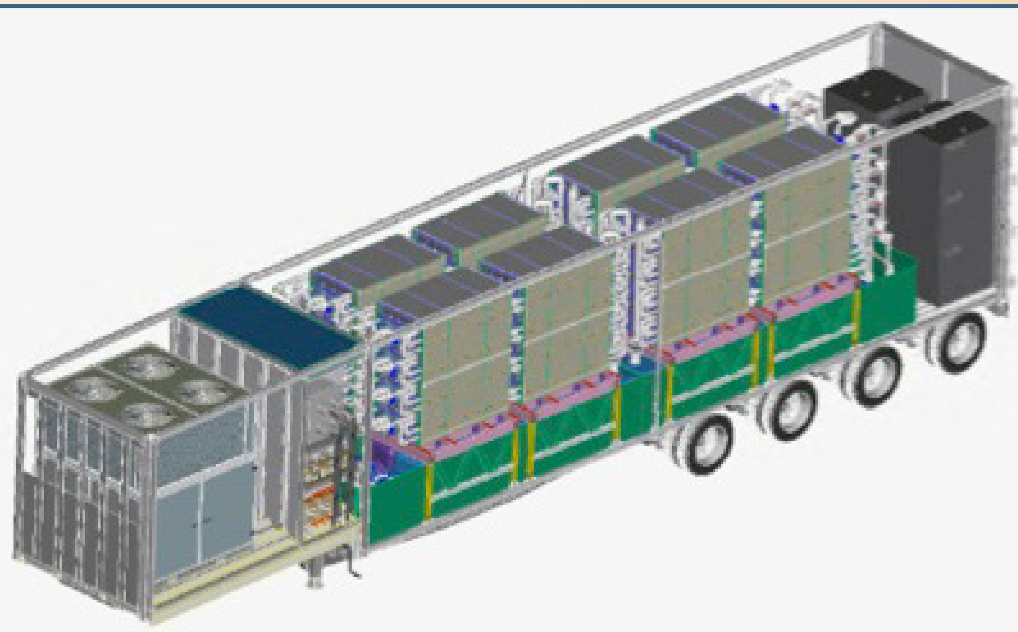
Denali Commission

Emerging Energy Technology Grant

An Investigation of Flow Battery Storage Systems for Islanded Grids in Alaska

A Project by Kotzebue Electric Association



Emerging Energy Technology Grant

Emerging energy technology is a critical phase in the development process of energy technology, linking research and development to the commercialization of energy solutions. Although the Arctic possesses bountiful energy resources, the Arctic also faces unique conditions in terms of climate, environment, population density, energy costs, logistics, and the isolated nature of electrical generation and transmission systems. These conditions, challenging under the best of circumstances, making the Arctic an ideal test bed for energy technology. Emerging energy technology provides a unique opportunity to meet Arctic energy needs, develop energy resources, and create global expertise.

In 2009 the Denali Commission, an independent federal agency in Alaska, released a public solicitation entitled the Emerging Energy Technology Grant (EETG). The EETG targeted (1) research, development, or demonstration projects designed to (a) test new energy technologies or methods of conserving energy or (b) improve an existing energy technology; and (2) applied research projects that employ energy technology with a reasonable expectation that the technology will be commercially viable in Alaska in not more than five years.

The following are the 9 projects funded under this solicitation:

Alaska SeaLife Center, Seawater Heat Pump Demonstration Project

Cordova Electric Cooperative, Psychrophiles for Generating Heating Gas

Kotzebue Electric Association, Feasibility of Solar Hot Water Systems

ORPC Alaska, Nenana Hydrokinetic Turbine

Sealaska Corporation, Commercial Scale Wood Pellet Boiler

Kotzebue Electric Association, Flow Battery Energy Storage Systems

Tanana Chiefs Conference, Organic Rankine Cycle Heat Recovery System

University of Alaska, Fairbanks, High Penetration Hybrid Power System

Kotzebue Electric Association, Wales Diesel-Off High Penetration Wind System

For further information, please visit the EETG program website at:

http://energy-alaska.wikidot.com/emerging-energy-technology-grant

Kotzebue Electric Association

Kotzebue Electric Association (KEA) is a rural electric utility cooperative, based in Kotzebue, Alaska. KEA has 840 members, and generates over 18 million kilowatt hours per year. For this project, KEA explored the use of flow batter technology in a rural Alaska environment. KEA submitted this project to the Denali Commission for consideration under the EETG program. KEA is the primary stakeholder in this project.

ACEP
Alaska Center for Energy and Power

University of Alaska Fairbanks
PO Box 755910
Fairbanks, AK 99775-5910
(907) 474-5402
www.uaf.edu/acep

About the Author

The Alaska Center for Energy and Power (ACEP) is an applied energy research group housed under the Institute of Northern Engineering at the University of Alaska Fairbanks. ACEP is serving as the program manager of the EETG program on behalf of the Denali Commission.

A key deliverable for each EETG project is a lessons learned report by ACEP. As the projects deal with emerging energy technology, providing lessons learned and recommendations is critical for understanding the future of the technology in Alaska, and the next steps needed in developing energy solutions for Alaska.

ACEP's technical knowledge and objective academic management of the projects, specifically for data collection, analysis, and reporting, are vital components to the intent of the solicitation.

An Investigation of Flow Battery Storage Systems for Islanded Grids in Alaska

A Project by Kotzebue Electric Association

Recipient:

Kotzebue Electric Association

EETG Funding:

$425,000

Project Timeline:

May 2010—December 2011

Report Overview

This report investigates the installation of a zinc-bromine flow battery system at Kotzebue. There is much interest in this technology for Alaska given the challenges of integrating intermittent energy sources into the many microgrids prevalent throughout rural Alaska. This report identifies the project participants and their roles and documents the development of the project, performance of the battery system factory acceptance test prior to shipment, and the installation and subsequent operational experience in Kotzebue. The report also presents findings based on the experience in the field, makes recommendations for the future direction of the flow battery project at Kotzebue and presents broader recommendations for other, future battery projects in Alaska communities.

For comprehensive project information, data, and report appendices, please visit the EETG program website at

http://energy-alaska.wikidot.com/emerging-energy-technology-grant

Project Introduction

The overall goal of this project was to test through demonstration advanced battery systems and their application to broader Alaska energy needs. Specific goals related to the installation of the system at KEA's powerhouse in Kotzebue included (1) increasing voltage stability, (2) increasing the efficiencies of operating diesel generators and (3) capturing excess wind energy during off-peak hours. The technology specified for demonstration was a 500-kW, 2.8-MWh Premium Power Transflow 2000 zinc-bromine flow battery.

Preproject activities including system characterization, modeling and site preparation commenced in 2009, with project activities formally commencing in March 2011. Factory acceptance testing of the battery was finalized in July 2011, and the battery system arrived in Kotzebue September 2011. Installation and attempted commissioning of the system commenced and continued through the spring of 2012, at which time the battery was returned to the vendor. Project activities under the EETG program formally ended in September 2012.

The roles and contributions of the four key participants in the Kotzebue project are as follows:

Kotzebue Electric Association

KEA submitted the project to the Denali Commission for consideration under the EETG program. KEA, the primary stakeholder in this project, is a rural electric utility cooperative in Kotzebue, Alaska that serves 840 members and generates 22 million kWh per year.

Premium Power

Premium Power was the supplier of the zinc-bromine flow battery tested in Kotzebue, which is the subject of this report. Premium Power was founded in 2002 and is based in Massachusetts.

National Rural Electric Cooperative Association

The Cooperative Research Network (CRN), the research arm of the National Rural Electric Cooperative Association (NRECA), contributed financial, technical and administrative support to KEA for the battery project. NRECA is the national service organization for more than 900 not-for-profit rural electric cooperatives (including KEA) across the United States. The mission of CRN is to monitor, evaluate and apply technologies that help electric cooperatives control costs, increase productivity and enhance service to their consumer-members.

Alaska Energy Authority

The Alaska Energy Authority (AEA) is providing $8 million in funding through the Renewable Energy Grant Fund (REF) program for a battery-wind-diesel project at KEA. A subset of this funding supported the deployment of the battery system discussed in this report.

Alaska Center for Energy and Power

The Alaska Center for Energy and Power (ACEP) provided technical support through data collection and performance monitoring of the KEA battery. While KEA was responsible for installation, maintenance, operation and instrumentation of the systems, ACEP was responsible for independent economic and performance analysis. This report is the final product of that effort.

Background Information

Energy Storage and Islanded Grids

A fundamental characteristic of a stable electric system is that the energy produced by the generating source, such as a diesel engine, has to match the instantaneous energy needs of the load(s) it is serving. In the absence of this instantaneous balance, either the load or the generator will suffer damage due to excess or deficient energy in the connected system. Electrical energy storage is a solution that can decouple the generator from the load and provide a "buffer" to maintain this instantaneous balance by absorbing or discharging energy as needed.

Stand-alone, remote community electric networks, ubiquitous throughout rural Alaska, are often referred to as "islanded" grids because of their electrical — although not necessarily geographical — isolation. Such grids are even more prone to large disturbances when intermittent generators, such as wind turbines, are added into the generation mix. Their variable output upsets the instantaneous balancing required for the stability of the electric system, which must maintain voltage and frequency within acceptable limits. The voltage and frequency excursions outside the design parameters of the power generation switchgear caused by the presence of variable generation, such as wind, has been the consistent experience of all islanded grids.

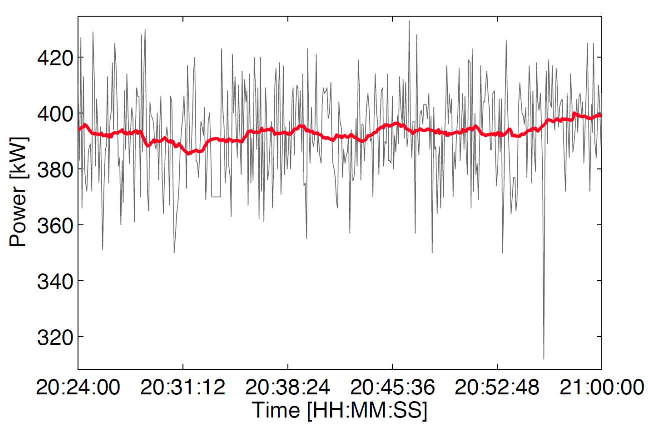


Figure 1. Typical wind variability measure at 1-second intervals (black) and smooted over 50 seconds (red)

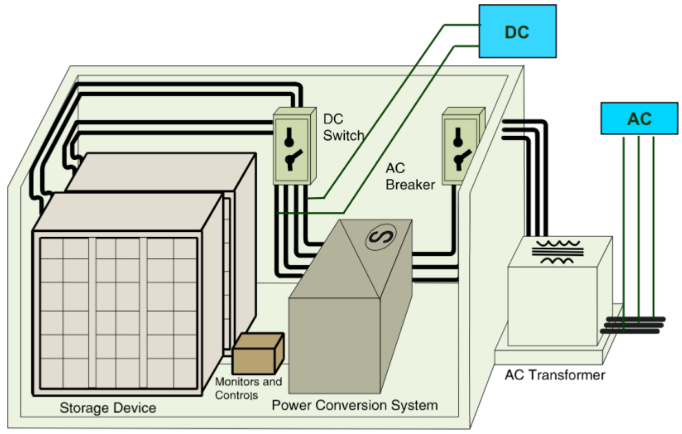


Figure 2. Battery system schematic showing key subcomponents[iii]

Figure 1 is a trace of typical wind variability in such a system, measured at 1-second intervals (black curve).[i] Smoothing out this variability (red curve, smoothed over a 50-second window) requires a fast response by other generation sources in the system to either increase or decrease output as needed. Such a fast response is usually beyond the operating capability of diesel generators.[ii] Battery storage systems, however, have an inherent ability to ramp their output up or down in a few milliseconds; this fast response capability makes them eminently suitable as a balancing resource in an island wind-diesel system, and their usefulness in balancing these electric systems has been the subject of considerable research and numerous technical papers.

Storage systems for balancing electrical output can be provided by several different technologies, but most have site or size constraints that limit their practical application in an electric supply system. Battery storage, although limited by some sizing constraints, provides the more flexible option, especially in the remote communities of Alaska. In such instances, battery energy storage offers several technology options that can be customized to a particular application's needs.

Battery storage systems have four essential components, regardless of the particular battery technology. As shown in Figure 2, the "system" is made up of a storage component, which is the battery itself; an electronic power conditioning component that matches the battery pack's electrical output to the voltage, current and frequency needed by the load(s); a monitoring and control component that maintains the health and safety of the battery; and other ancillary equipment including switchgear, transformers and other components necessary for the battery system to function.

Flow Batteries

In the family of battery types, flow batteries are unique. As the name implies, their electrolytes are in a liquid state. Their storage component consists of two electrolyte reservoirs from which the electrolytes are circulated by pumps through a cell where the electricity is generated. The chemical energy in the liquid electrolytes is converted to electricity in the cell; at that point, the process of converting that electricity to useful voltage and current is similar to all other battery systems.

The schematic in Figure 3 illustrates the principal components of a typical flow battery. As shown in the figure, two electrolyte tanks are on either side of four electricity cells in the middle. The number of cells determines the power of the battery; a large battery such KEA's could have several hundred cells. The battery also needs pumps and valves as shown in the schematic to circulate the electrolyte through the cells and to modulate that flow as needed. The quantity of electrolyte generally determines the amount of energy the flow battery can store or discharge. Consequently, it is at least theoretically possible to increase the energy storage capacity of the battery by increasing the quantity of stored electrolyte.

Current development effort[v] is mostly focused on two types of flow batteries: zinc-bromine and vanadium redox.[vi] While both are categorized as flow batteries, there are major differences between the two. The zinc-bromine battery primarily deposits zinc in the cells during its operation, whereas the vanadium redox battery works purely by the interaction between the two active fluids as they pass through the cells, and no residual material is deposited in the cells. System developers are pursuing both types of flow batteries, but neither type has yet to achieve full commercial maturity.

Key advantages and disadvantages of using flow battery technology in electric utility stationary applications are briefly outlined below:

Advantages of Flow Batteries

1. Flow batteries offer larger energy storage capacities than other battery technologies such as lead-acid or Li-ion batteries. Hence, flow batteries are called "energy" batteries because they are suitable for applications where more than four hours of energy storage are needed.
2. It is possible to increase storage capacity after commissioning the battery by adding additional storage tanks for the liquid electrolyte.
3. Fully discharging flow batteries is theoretically possible in routine operation. Repetitive deep discharges are not desirable or feasible with most other battery technologies and adversely impact their useful life.

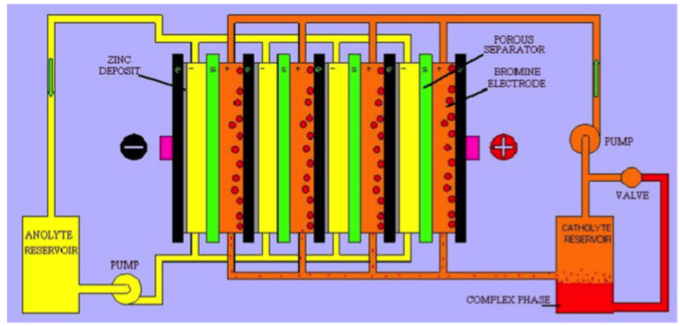


Figure 3. Schematic of a zinc-bromine flow battery[iv]

Disadvantages of Flow Batteries

1. High capital cost relative to the benefits and the round-trip efficiency penalty[vii], which is difficult to estimate in the absence of field operating data, is a significant factor in life cycle cost unless the energy used is free or otherwise wasted.
2. Most zinc-bromine and vanadium redox flow batteries require substantial auxiliary systems, such as pumps for circulating the liquid electrolyte and for cooling. There is also significant piping to transport the liquid from storage tanks to the stack and back; incorrectly designed and engineered pipes could lead to a leaking system.
3. In zinc-bromine batteries, metallic zinc is deposited in the stack of the battery during the discharge cycle, and this deposit needs to be removed by a periodic "stripping" cycle. This requires external energy and contributes to the other auxiliary losses, which leads to lower efficiency of the overall battery system.
4. Liquid electrolytes are hazardous materials and need to be handled in accordance with their recommended guidelines and disposed of accordingly at the end of life of the battery system.

ACEP Flow Battery Research

ACEP and its predecessor, the Arctic Energy Technology Development Lab (AETDL), have been involved in flow battery research since 2006. To date, six vanadium redox systems have been delivered and tested in Alaska. The first five systems were purchased from, or provided by, VRB Power. The final and current system was purchased from Prudent Energy. These systems were in the 5-kW class, with storage ranging from 10 to 20 kWh. The systems were all tested in a laboratory setting and subjected to continuous charge and discharge cycles.

Early systems from VRB can best be described as pre-commercial. They were of professional quality but contained significant rough edges and were bristling with instrumentation related to remote monitoring and control. The transition from charge to discharge was a distinct event and not seamless. Additionally, each system had quality control issues. The current system from Prudent Energy was purchased by the University of Alaska Fairbanks (UAF) Chukchi Campus in Kotzebue and delivered to ACEP in Fairbanks for qualification and testing.[viii] It is technologically more mature; the stack module and controller are much more representative of a commercial, mass-produced product. The system, when treated as a black box, acts very much like a conventional battery. Change from a charge to a discharge state is instantaneous and seamless.

These systems have generally performed well but have not been trouble-free. These systems meet their promised specifications; the turnaround efficiency is typically in the mid-70th percentile and the batteries have experienced minimal degradation despite demanding charge and discharge cycles. As outlined below, however, there have been a variety of failures, mostly related to quality control and the balance of plant (the supporting or auxiliary components not included in the primary system itself).

Significant issues include leaks, stack failures and quality control. To date, every system has leaked and cleanup is costly. Leaks have occurred in fittings, storage tanks, pumps and the stacks themselves. All systems, as currently designed, have the balance of plant situated at or below the electrolyte level such that a leak in one of the auxiliary components can lead to the complete loss of electrolyte. It should be noted, however, that the current system from Prudent Energy operated for nearly a year before losing a pump seal, which is a significant improvement in reliability from previous iterations of the technology.

Three stack failures occurred, one due to an internal leak that resulted from improper assembly, one due to a failure to remove shipping material and one due operator error. Additionally, there have been reliability issues with the chargers, control computer and other circuitry related to the power electronics.

ACEP's testing highlights that while there are theoretical advantages to flow batteries, there have been hurdles in their practical implementation since their earliest development stages dating back to the 1980s; these technical challenges still persist and have not been overcome.

Other Technology Options

Energy storage systems could play a significant role in reducing a remote Alaska community's reliance on fossil fuels and increasing the reliability of its electric grid. This is especially applicable for the communities that have or will have an increasing penetration of renewable resources such as wind, as in Kotzebue's case. As discussed earlier, these island grids may need the rapid damping and balancing capabilities that storage systems such as batteries and flywheels provide to operate stably and/or reliably.

Although this report focuses on flow batteries, it is pertinent to note that over the last 25 years the Department of Energy (DOE) Energy Storage Program has funded the development of several types of batteries and other storage technologies besides zinc-bromine, including sodium-sulfur, lead-acid, Li-ion and flywheels. Of these technologies, sodium-sulfur and lead-acid are both commercially mature and are used in a large number of battery storage projects around the world in a variety of stationary applications. In addition, modern composite flywheels are in the advanced commercialization phase in the U.S., with several successful demonstrations in California, New York and Pennsylvania.

Other non-battery storage options are also being explored to either capture excess wind-generated electricity in thermal storage or use similar heat sink devices to manage the frequency excursions caused by high penetration of variable wind generation in small grids. The two projects in the Chaninik region are examples where distributed intelligent load control of electric thermal storage (ETS) units, hot water heaters, freezers and electric heaters is being investigated as an alternative strategy to increase renewable penetration.[ix]

The high penetration of variable renewable resources in the electric grid to reduce dependence on liquid fossil fuels is particularly evident in islanded grids and has led to greater interest in storage technologies. For example, in Hawaii over 40 MW of battery storage systems, each with one hour or less of storage, have been installed in the island chain within the last two years. The battery systems support either wind or photovoltaic installations to mitigate the effect of their variable output on each island's electric grid, an application very similar to Kotzebue's intended application. Notably, the Hawaii battery systems are non-flow technologies and include a mix of advanced lead-acid and new Li-ion battery systems.

Two other battery storage projects along with the Usibelli mine's flywheel project are relevant to this discussion in light of their technical characteristics and their successes in meeting application requirements and owner expectations. In terms of their size and energy capacity, these projects lie on the opposite ends of the spectrum. The Metlakatla battery energy storage system (BESS) is rated at 1.2 MW/1.4 MWh.

The Usibelli mine flywheel is 5.2 MW, but it puts out power in 3-second bursts, so its actual energy output is very small — only 4.33 kWh. The Fairbanks BESS, rated at 46 MW/17 MWh, represents the other end of this spectrum. Both the Metlakatla and Fairbanks experiences are described below.

Metlakatla BESS: Metlakatla Power & Light

Although the climatic conditions and geography of the two communities are vastly different, there are similarities in the Metlakatla and Kotzebue electric grids and the resident communities. Both electric systems have a peak in the 3- to 4-MW range and a resident population of about 3,500. Both electric systems experience intermittent power swings, albeit caused by different sources of energy. In the case of Metlakatla, the local lumber mill operates on a 14-hour schedule, with large 400- and 600-kW motors. These motors operate randomly, usually within minutes of each other, causing 900-kW power swings that the hydro generation, which is the backbone of the Metlakatla system, could not effectively compensate for. In Kotzebue, power swings are caused by the presence of wind turbines with a somewhat random pattern of operation, although these swings are not as dramatic as those in Metlakatla. In Metlakatla, the BESS has proved very effective[x] in smoothing out the power fluctuations and saving the community over $350,000/year in diesel fuel costs by eliminating the 3-MW diesel gen-set that was previously doing what the BESS does. However, two important factors contributed to the economic viability of the Metlakatla BESS:

1. The system offset a real expense of $350,000 annually incurred by the community to purchase fuel for the diesel that the BESS displaced. This led to a 3-year simple payback for the capital investment in the BESS system.[xi]
2. The energy to charge the battery was supplied by two hydro generating units — a steady source of non-fossil energy — owned by Metlakatla Power & Light.

The design of the Metlakatla BESS was based on an analysis of the magnitude and frequency of the power swings caused by the lumber mill motors. The on-off state of the motors was simulated and modeled to estimate the MW size and MWh energy specifications for the BESS. Once these parameters were established, the next task was to match the daily cycling frequency to a suitable battery string and power conditioning system. The BESS was built and installed by General Electric Company (GE) in partnership with GNB (now Exide Battery). The close working relationship between GE and GNB resulted in a battery system that far exceeded its operational expectations. The battery was originally warranted for eight years, but it provided useful service for 12 years. The longevity of the battery system can be directly attributed to (1) GE's understanding of the need to control the battery within its operational limits and the correct (or conservative) estimate of the number of cycles the battery would experience during its operational life and (2) GNB's selection of a proven battery chemistry and a robust cell designed to survive the high number of cycles the battery would experience. A related contributory factor was the prior experience (going back to the mid-1980s) of GE and GNB in supplying large utility application batteries.

Fairbanks BESS: Golden Valley Electric Association

Commissioned in 2003, the Fairbanks BESS holds the Guinness World Record for the world's most powerful battery.[xii] Because there is no similarity between the size of this battery and the type of battery that is needed in Kotzebue, we do not offer the technical details of the Fairbanks BESS; instead, we focus on the lessons learned from the successful implementation of the Fairbanks BESS as examples for implementing other battery storage projects in Alaska.

As in the case of the Metlakatla battery project, the first task was to identify the functions the battery would perform in the GVEA system. It was determined that there were seven discrete functions the battery system would have to perform to meet GVEA's storage needs. The seven requirements were described in a Request for Proposals (RFP) that was released to potential battery system vendors without indicating any preference for a particular type of battery chemistry or storage technology. That choice was left to individual system suppliers based on their judgment of the storage technology that would best meet GVEA requirements and provide the lowest levelized cost of electricity (the price at which electricity must be generated from a specific source to break even over the lifetime of a project). GVEA eventually selected a battery system designed and built by ABB and Saft; the system uses power electronics and controls from ABB and a nickel cadmium battery designed and built by Saft. This procurement approach allows the owner (utility) to focus on refining its needs and does not burden it with analyzing the myriad factors that go into selecting the right storage technology. That choice is rightly left to the system vendor, who is not only in the best position to make that determination but also has the fiscal responsibility of warrantying its performance as specified by the owner.

The Fairbanks BESS has performed as it was designed to and has met its operational requirements during its time in service. It is noted here as another example of a successful implementation of battery energy storage in Alaska where the owner clearly delineated storage needs and selected system vendors that offered proven technology solutions to address those needs.

Usibelli Flywheel: Usibelli Coal Mine

The Usibelli coal mine started using an all-electric dragline in the late 1970s and draws its power from Golden Valley Electric Association (GVEA). The 6 MW of power the dragline uses when it is loading imposes a significant cyclic load on the GVEA grid. A slow-speed steel flywheel was installed in 1982 to mitigate the effects of this large cyclic load. The flywheel puts out 5.2 MW in 3-second bursts when the dragline is loading and absorbs about 2 MW when the dragline unloads. This "peak shaver" flywheel system has worked effectively in the Usibelli application.[xiii]

Today's flywheel systems offer similar services to the electric grid by providing lots of power but small quantities of energy to meet balancing needs such as frequency regulation and spinning reserve. Flywheels could be a viable storage option in Alaska communities and could broaden the portfolio of storage technology options available today.

Project Review

Kotzebue is a town of 3,200 people on a narrow spit of land that protrudes into Kotzebue Sound in Northwest Alaska (Figure 4). Access to Kotzebue is limited to regular commercial air service from Anchorage and Nome and seasonal barge service. KEA, the electric utility for the community of Kotzebue, sees an average load of 2.5 MW and a peak load of 3.7 MW. Power is supplied by a diesel generation plant, capable of providing over 10 MW, and a wind farm situated approximately 4.5 miles out of town. Installed capacity at the wind farm is 2.95 MW. The farm consists of fifteen 15 66-kW Entegrity Wind System (EWS) turbines, one 100-kW North-Wind 100 turbine, one 65-kW Vestas turbine and two 900-kW EWT turbines.

Figure 4. Map of Kotzebue, Alaska

Project Development

The KEA battery project discussed in this report is a component of a broader medium-penetration battery-wind-diesel project, the primary activity of which was the installation of the two EWT turbines noted above; the project was funded through Rounds One and Three of the AEA REF program. The stated intent of a battery component of the project was to (1) increase voltage stability, (2) increase the efficiencies of operating diesel generators and (3) capture excess wind energy during off-peak hours. Specific to (1), KEA stated that it has seen instantaneous wind penetration levels of over 80 percent; an installed battery system would allow KEA to provide frequency regulation and spinning reserve to utilize higher penetration levels and maintain system stability. Furthermore, a battery system would allow for more efficient diesel generator dispatch and would allow KEA to capture off-peak wind generation, ultimately reducing expensive diesel fuel consumption by KEA for power production.[xiv]

In addition to the AEA REF funding for the battery system, KEA also received funding from the Denali Commission EETG program; the KEA battery project was selected for funding under the EETG program to test through demonstration advanced battery systems and their application to broader Alaska energy needs. Given the relevance of energy storage to islanded grid application, the lessons learned from this project would be invaluable to future application of this technology across the state.

The original flow battery technology investigated for the KEA battery system was a VRB vanadium redox battery. VRB performed detailed engineering assessments of the KEA system and had worked out product specifications, but during the process of finalizing design and acquisition, VRB went bankrupt. Despite this setback, another product became available through a partnership with the NRECA's CRN.

In 2008, the CRN applied for an American Reinvestment and Recovery Act (ARRA) stimulus grant to purchase and test flow batteries. CRN's proposal was for the deployment of Premium Power zinc-bromine battery systems at nine locations around the country, including Kauai Island Utility Cooperative (HI), Central Electric Power Cooperative (SC), Seminole Electric Cooperative (FL) and KEA. CRN was interested in the deployment of advanced batteries to strengthen rural electric systems and to maximize the value of renewable energy. This proposal was ultimately not funded; however, KEA and CRN were able to procure a battery from Premium Power with the same terms and conditions established through the anticipated ARRA program using the funds dedicated towards the Kotzebue project outlined above[xv].

Project Specifications

KEA was awarded $425,000 under the EETG program for the battery system, with $327,000 budgeted for battery purchase and $98,000 designated for engineering, equipment (e.g., switchgear), project management, site work and preparation, and battery warranty.[xvi] Key project milestones included factory acceptance testing, shipment, installation and commissioning, and demonstration operation.

The Premium Power Transflow 2000 battery used in this demonstrated was a 500-kW, 2.8-MW-hour zinc-bromine battery, a fully integrated system composed of energy storage, power conditioning, battery control and thermal management packaged into a 53-foot trailer (Figure 5). High-level specifications of the Transflow 2000 are given below:

The original performance period for this project was March 1, 2010 to December 31, 2011. Battery shipment was anticipated to take place during the summer of 2010, with installation and operation commencing in the fall. Because of various delays and project results (discussed below), the final performance period was March 29, 2011 to September 30, 2012.

Factory Acceptance Testing

The first project milestone was a review of the battery at the Premium Power factory in Massachusetts. KEA had contractually established a Factory Acceptance Test (FAT) procedure with Premium Power, KEA was to attend the FAT at the Premium Power factory in Massachusetts and sign off on accepted results before authorizing shipment to the site.

In the spring of 2010, KEA received production status reports from Premium Power estimating a unit completion date at the end of May 2010, with testing beginning in June 2010. This timeline was in accordance with the original anticipated project performance period. Initial testing of the battery by Premium Power preceding the FAT, however, indicated the need for fluid upgrade in the unit. This delay caused the battery to miss the 2010 summer barge season.

The performance period of the project was updated to March 29, 2011 to December 2011. It was anticipated that the FAT

Energy Storage Capacity	2.8 MWh (~5 hours of storage)
Maximum Continuous Power Delivery	500 kW
Voltage Input/Output	480 VAC, 60Hz, 3-phase
Power Factor (Input)	± 0.95

Table 1. Transflow 2000 General Specifications

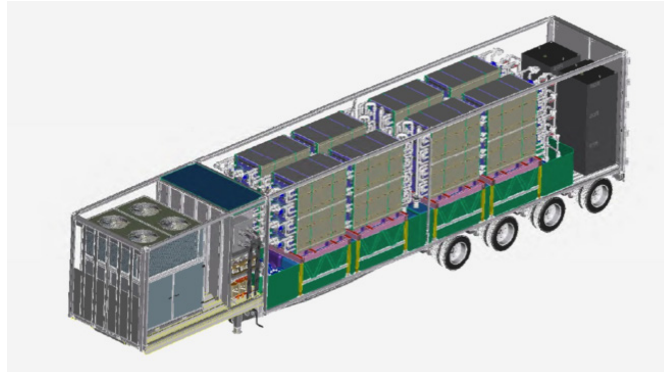


Figure 5. Premium Power Transflow 2000[xvii]

would occur in the spring of 2011 and the battery would be shipped on the first barge to Kotzebue, arriving in July 2011. It was also anticipated that despite missing a winter of on-site testing and operation, KEA could complete testing on the unit before the original end of the performance period, December 2011, given the long lead time and opportunity to further prepare the site for battery integration.

FAT Results

The final FAT took place July 18 to July 21, 2011. A summary of the KEA FAT report[xviii] is as follows:

The KEA representative inspected the Transflow 2000 unit at the Premium Power factory in accordance with the test protocols outlined in Table 2. The unit was accessed using a web-based interface, and charging was observed remotely from the company manufacturing facility. The unit was in operation and testing lasted for 12 weeks. All eight stacks were in place; power to the unit was provided with a 1-MW Caterpillar diesel engine, and load was applied through multiple load banks.

The battery showed above-average efficiency measurements of 63 to 70 percent. However, Premium Power indicated that the actual efficiency might be as high as 90 percent on the AC side of the bus. Table 3 is a summary of the data collected during different runs.

Though the battery did not provide the advertised capacity of 2.8 MWh, it exhibited approximately 2 MWh during charging and provided only about 1.6 MWh in discharge. There appears to be significant variability in the measured efficiency of the battery from cycle to cycle. It is not clear if each cycle began from a totally discharged state, or some other standard state, or if the battery discharge stopped at a standard state. In none of the cycles was a charge rate of 313 kW maintained for 10 hours; the average charge time was about six hours at 313 kW. Discharge times were also shorter than anticipated; runs 5 and 6 indicated discharge times of just over three hours.

Energy, Power, and Efficiency	Parameters	Results
Full Charge/Full and Fractional Discharge Tests	• Perform at 100% full-rated input/output • Set discarge rate to 100% • Record full-cycle run time (both charge and discharge states) under full load • Repeat at 60% and 30% rated output	• Verify charge rate of 315 kW per hour over 10 hours • Verify discarge rate of 500kW per hour for 5 to 6 hours
AC Round Trip Efficiency	• Perform at 100% full-rated input/output • Record input root mean square (rms) voltage and current • Record output rms voltage and current • Record temperatures • repeat at 60% and 30% rated output	• Verify that AC round trip efficiency at 100% full-rated input/output is between 63% and 70%
Functional Use Case Test	**Parameters**	**Results**
Response to Remote Commands via DNP3	• Perform at scheduled input/output • Effect a charge, discharge or standby condition through DNP3 command or schedule • Time duration of 5 minutes per request	• Verify that TF2000 can respond to commanded operation or scheduled commands
Reliability	• Preprogram a three-day schedule into the TF2000 to operate various quadrants at various charge and discharge conditions for a variety of preprogrammed durations	• Verify that TF2000 can operate autonomously for a period of three days

Table 2. Factory Acceptance Tests Specifications

The findings of the KEA representative after FAT testing are as follows:

> *"If this were a commercial utility purchase of a standard product, the responsible action would be to decline acceptance of the unit based on a failure to perform to expected levels. However, this project at Kotzebue Electric Association is funded largely through funds intended to demonstrate pre-commercial technologies and evaluate their possible use in Alaskan communities. The objective of the project is to test the hardware and assess its level of performance."*

Despite concerns for underperformance with regard to desired specifications, KEA accepted the Premium Power battery for shipment because of its overall functionality and relevance to a demonstration program.

Shipment

The Premium Power battery system was shipped after acceptance of the FAT via truck to Seattle, then barge to Kotzebue. While the battery system was en route to Kotzebue, the project site was prepared for installation and integration. The flow battery arrived in Kotzebue on Sunday, September 25 and was moved into place at a KEA substation on Monday, September 26.

Upon arrival, it was discovered that the battery system had not been adequately packaged for shipment. The system had not been shrink-wrapped or otherwise prepared for marine shipment, which resulted in significant corrosion of bare metal elements from exposure to salt water and other environmental damage. Only basic system cleaning could be conducted in the field before installation could commence. It is suspected, but not confirmed, that this damage played a role in commissioning troubles (discussed below).

Commissioning Activities

According to the warranty conditions of the battery system, a Premium Power representative was required to be on site during each installation and commissioning phase. The following is a summary of the first three commissioning trips undertaken by Premium Power:

1. October 1–7, 2011: The battery was inspected for shipping damage. The cooling system was filled with ethylene glycol, and the chiller and circulation pump were commissioned. The battery was also filled with electrolyte solution.
2. October 22–29, 2011: Commissioning of electrical system including power, controls and communications began. Leaks in the PVC pipe/tubing to stacks were detected. Control communication (serial DNP 3.0) to the supervisory control and data acquisition (SCADA) [ixx] programmable logic controller (PLC)[xx] was not fully functional. Remote access via VPN to battery controller was established.
3. December 10–17, 2011: Half of the battery electrolyte hoses were replaced with Teflon material hoses. Initial tests showed no leakage compared to PVC hoses.[xxi]

The next steps for commissioning were identified as follows:

1. Return in late January 2012 to complete swap out of PVC hoses for Teflon hoses.
2. Complete commissioning of control communications between SCADA PLC and battery controller.
3. Install supplemental heating system for winter protection.
4. Complete commissioning of total battery and begin charge/discharge cycles.

The next commissioning trip, intended for January, was canceled because of extended cold weather below -30°F. The final commissioning trip undertaken by Premium Power, beginning on March 22, was reported as follows:

> *"Communications were reestablished with the unit, using an isolation card. The KEA SCADA system will communicate with the battery through a PLC and RS 232 connection, while Premium Power can communicate with the battery directly over the Internet. On March 27, 2012, it was indicated that communications have been established with PP headquarters, but it was not clear if this meant that PP could "see" the KEA SCADA system, or if the KEA SCADA system could communicate with the Internet.*
>
> *However, the battery has developed some unexpected leaks, and electrolyte was discovered in the secondary containment in several places. The most significant leak was about 45 gallons, in quadrant where all the electrolyte had been drained out of the stack — indicating that the leak had occurred somewhere in the bottom of the unit. However, the exact location of the leak was not determined. It is thought that this leak may have been caused by the extreme cold weather affecting seals associated with hose clamps — the plastic pipes and hoses under the clamps are likely to contract more in cold weather than the metal bands of the clamps, and so a leak may have developed in one of these areas. The new Teflon tubes were all fine, but other parts of the system are made with PVC piping and rubber hoses. PP technicians intend to return to company headquarters and come up with a solution to this issue. They will then return to Kotzebue and make the necessary repairs."*

After the final unsuccessful commissioning trip, it was decided to put the project on hold and return the battery to Premium Power for redesign. This decision was jointly made by KEA and Premium Power, who, in addition to facing the technical challenges of field commissioning, was facing corporate reorganization (see below). The challenge of commissioning in the field was attributed to many factors, including weather, the possible corrosion of the system during shipment, materials, remoteness from vendor support and, primarily, a design that did not allow for field access to internal system components (see below).

Future Plans

Premium Power went through a corporate reorganization in

Run #	Kw-hr In	kW-hr Out	Efficiency
Run 1	1909.3	1273.067	67%
Run 2	2133.617	2047	96%
Run 3	1956.25	1593.1	81%
Run 4	1997.983	1444.8	72%
Run 5	1909.3	1800	94%
Run 6	1951.033	1508.333	77%

Table 3. Factory Acceptance Testing Efficiency Results

mid-2012. It is likely that new leadership will be re-evaluating the engineering readiness and field worthiness of the battery system as it exists today. The experience from the attempted commissioning of the battery in Kotzebue could play a significant role in the choices that the new management at Premium Power is likely to make in the redesign of the system. The practical constraint in the physical layout of the battery system is that there is restricted access to the inner components of the system, which makes it difficult to troubleshoot and perform field repairs. This created an insurmountable situation in the Kotzebue setup. Further, the present configuration of the Premium Power battery is a single, trailer-mounted, transportable design, but the shipping to Kotzebue required a total of five separate shipping units — four to accommodate the electrolyte containers and one for spare parts. It is also likely that Premium Power will move away from the trailer-mounted Transflow 2000 design and reconfigure the next generation system to be a smaller 125-kW package, which could simplify the shipping logistics.

KEA is currently under discussion with Premium Power to provide a redesigned unit to site. Since the Denali Commission EETG program ended on September 30, 2012, funding will not be available for future project deployment. The future status of the various funding sources involved in this project is unknown at this time.

Findings and Recommendations

This section presents findings and recommendations, both specific to Kotzebue and more generalized for other remote communities where battery storage is considered as a future technology option.

Findings and Recommendations for Kotzebue

This report concludes that the Premium Power battery system was not ready for a full-scale field demonstration[xxii], especially in a remote location such as Kotzebue. Specific issues that were identified in the July 2011 FAT report and the quarterly progress reports written after the unit was delivered to Kotzebue corroborate this finding.

The FAT report specifically found:

1. The system did not discharge its rated 2.8 MWh of energy and achieved only 1.6 MWh of available energy.
2. Discharge time of three hours instead of five and six hours was shorter than expected.
3. FAT data indicated that the efficiency of the system may be as much as 20 points lower than Premium Power's estimates. Premium Power could not provide a reason for the lower ranges.

The quarterly reports also indicate that the Premium Power field technicians were unable to fully repair the damage to the system that was sustained during transit and could not establish communication between the battery and KEA SCADA. In the absence of this communication link, the battery system could not meet its basic functional requirement in the Kotzebue electric grid.

The Premium Power system has been returned to the vendor and it is being re-engineered into a smaller 125-kW system; Premium Power intends to send it back to Kotzebue. This report recommends that the re-engineered system should not be brought back to Kotzebue until it can produce the original power rating of 500 kW.[xxiii]

The requirement to produce 500 kW, as originally specified, is critically necessary for the battery system to stabilize and balance the Kotzebue electric grid effectively; with additional new wind generation to the Kotzebue grid, the reduction of the battery power from the original 500 kW to 125 kW (after its redesign) would render it ineffective in providing both stability and balancing functions to the Kotzebue grid.

Because of the experience at Kotzebue, this report recommends that the re-engineered system meet the following milestones either at the Premium Power factory site or at a third-party test site:

1. The system must operate according to a specified charge-discharge profile continuously for a period of 30 days. During this time, the system must meet a minimum efficiency of 70 percent and an availability of 90 percent.[xxiv]
2. The 30-day test period should be completed without leaks from any component of the system, including the stacks, valves, pipes, connectors and couplings.
3. The system must be remotely connected to the KEA SCADA (or its simulated equivalent) and respond to all commands it receives from it — including remote startup and shutdown — within the time frames specified during the 30-day test period.

In addition to these performance-related milestones, Premium Power should identify the physical location of all subsystems within the trailer and satisfactorily demonstrate that these are accessible for maintenance and repair in the field by Premium Power technicians, using equipment that would reasonably be expected to be available at the Kotzebue site.

Prior to shipping the system, Premium Power must satisfactorily demonstrate that it is capable of packaging, transporting and installing the system at Kotzebue in compliance with KEA requirements. It must also demonstrate that it is capable and willing to support the necessary technical staff at Kotzebue for a period of eight weeks if the system is reinstalled at Kotzebue.

Recommendations for Future Projects in Alaska

There are two specific recommendations for future battery storage projects in other remote Alaska communities. The first is to continue tracking the progress of flow battery technologies by annual technology assessments and laboratory evaluations. The technology assessments should be geared to assessing the readiness of the technology for Alaska applications and report results of laboratory testing. Such assessments should be conducted for a period of three to five years.

The second recommendation recognizes the desire by the remote Alaska communities to introduce new battery technologies to reduce their dependence on diesel fuel and increase their utilization of renewable energy technologies. However, the selection of energy storage technologies and their integration into the community power grid needs careful and informed consideration. The emerging technology landscape of battery systems is fairly complex, and remote communities need technical support and guidance to determine when and if battery storage is the correct technical and economic solution for their specific conditions.

It is proposed that guidelines be developed that can be used by the communities to implement future projects. These guidelines would allow the communities to objectively evaluate suitable battery technologies on a project-specific basis. The guidelines would include assessing the maturity of the vendor's product and evaluating the vendor's ability to successfully support the project through the installation, startup and acceptance phases and address other technical issues that the community may otherwise overlook. Incorrect or misleading information about technology readiness and performance occurs frequently in emerging technologies, and these guidelines would help the communities make informed decisions that align with their project's objectives.

The stepwise guidelines for implementing future projects are listed below:

1. Ascertain that energy storage is the appropriate solution. Assess the existing and future power generation sources of the community and determine if battery storage is the preferred technology option. Power generation sources that include hydro or wind generally indicate that energy storage improves efficiency and/or reliability.
2. Site-specific assessment. Undertake a detailed study of the site-specific parameters to determine the size (power and energy), and location of the energy storage system.
3. Energy Storage Technology Selection. Select the storage technology that can satisfy the site-specific requirements. Take into consideration not only the size and technical-functional requirements identified in Step 2 but also the commercial maturity of the selected technology and the capabilities of the vendors who can supply the desired system. The storage technologies under consideration should include not only different battery types but other energy storage systems, including flywheel systems, as well.
4. Economic Feasibility and Financing Options. Determine the economic feasibility of the project based on the life cycle cost of ownership of the storage system by the community. The life cycle costs are based on capital and operations and maintenance (O&M) costs incurred by the community to own and operate the energy storage system. This information can then be used to evaluate and identify the appropriate funding source(s) to implement the storage project.

This four-step process brings a structured approach to evaluating energy storage opportunities and should be a collaborative process between the community and an organization that has relevant technical capacity, expertise and knowledge of operating conditions in Alaska; this will allow the community to make an informed choice in an often confusing technology landscape.

The commercial maturity of the battery system and the ability of the vendor to provide effective field support are both important ingredients for the successful implementation of a storage project, as was evident from Kotzebue's recent experience. The Metlakatla experience underscores this assertion. GE, which was the system integrator for the Metlakatla battery system, stationed its project manager on site in Metlakatla for the duration of the construction and startup phases of the project. This ensured that the project adhered to its planned milestones, and the project manager resolved all the unforeseen issues as expediently as possible. In both the Metlakatla and Fairbanks projects, a key ingredient to success was clearly identifying the owner's storage needs and selecting system vendors that offered proven technology solutions to address those needs.

References and Notes

[i] Wind variability data taken from the Unalakleet wind farm bus and provided by AEA. No similar data is available for the KEA system; however, the Unalakleet data indicates typical variability in remote Alaska wind systems.

[ii] Diesels, which modulate their output up or down rapidly, risk stress

due to fluctuating operation, thus reducing their useful life. In addition, diesel generation can see decreased efficiency in systems with intermittent generators (e.g., wind) as the diesels are run at lower load to ensure there is sufficient spinning reserve for sudden decreases in intermittent generation output.

[iii] Image from Sandia National Laboratory reporting.

[iv] Image courtesy of the ZBB Energy Corporation.

[v] The original development of zinc-bromine battery technology was undertaken by Exxon and Gould in the mid-1970s and continued until early 1980s. Their research and development overcame the initial challenges and laid the foundation for further work to proceed. In the mid-1980s Exxon licensed its technology to Johnson Controls, Inc. (JCI), Studiengesellschaft für Energiespeicherund Antriebssysteme, SEA (Europe), Toyota Motor Corporation and Meidensha Corporation (Japan) and Sherwood Industries (Australia). JCI continued development of this technology through funding from the U.S. Department of Energy Utility Battery Program at Sandia National Laboratories. Significant improvements in the stack design and charge management were made during this period, but JCI sold its interest to ZBB Energy Corporation and Powercell Corporation in the early 1990s. The battery system sold by Premium Power traces its origins to the original work at JCI.

[vi] The term "redox" is obtained from a contraction of the words "reduction" and "oxidation."

[vii] Battery round trip efficiency is the amount of energy recovered from the storage device divided by the energy put into the device.

[viii] The total EETG award directed to KEA was $500,000; $75,000 was sub-awarded to UAF by KEA for research and reporting on other near-commercial battery technologies under development, including the testing of a 5-kW Prudent Energy battery system purchased by the UAF Chukchi Campus. This battery was tested by ACEP; a detailed testing report can be found at http://energy-alaska.wdfiles.com/local--files/flow-battery-energy-storage-systems/ACEP-VRBReport_5.2012.pdf

[ix] Intelligent Energy Systems, LLC's Emerging Energy Technology Grant Fund Application to Alaska Energy Authority, March 9, 2012, for "Self Regulated Wind Diesel Grid Using Electric Thermal Storage Units". www.akenergyauthority.org/EmergingEnergyTechologyFund/EETF-AC_Stage1_Review/Abstracts/049.pdf

[x] Other options besides the BESS were evaluated in the early conceptual phase of the Metlakatla project by General Electric. These were subsequently discarded in favor of the BESS.

[xi] There was no federal or state funding support for the purchase of the battery.

[xii] The Fairbanks BESS system holds the Guinness World Record for the world's most powerful battery, discharging 46 MW of power over a five-minute period in December 2003 (www.battcon.com/PapersFinal2002/DeVriesPaper2002.pdf). The State Grid Corporation of China (SGCC) and BYD commissioned a 36-MWh battery system (36 MW of power provided for one hour), Hebei Province of China, in January 2012 (www.popsci.com/science/article/2012-01/china-builds-worlds-largest-battery-36-megawatt-hour-behemoth). Japan is reported to be constructing a 60-MWh system in the Hokkaido prefecture by March 2015 (www.bloomberg.com/news/2013-04-17/japan-to-install-battery-in-hokkaido-to-ease-solar-pressure.html).

[xiii] The functionality of this flywheel is very similar to adding storage in remote communities where renewable energy sources such as wind, create similar fluctuations that cannot be managed effectively without a storage system.

[xiv] The AEA REF funding for the broader KEA project totals $8,000,000 with $1,559,306 dedicated to the battery system project component. To date, approximately $140,000 has been utilized for battery shipment, and $100,000 for site preparation and system integration.

[xv] The purchase price of the Premium Power battery is estimated to be $1,050,000 ($1,208,600 after delivery and installation). The purchase contract, however, required successful commissioning before battery purchase was finalized. A down payment of $250,000, paid by the CRN, was required before delivery of the battery. KEA also has a funding from the federal Clean Renewable Energy Bonds (CREBs) program for battery purchase.

[xvi] EETG funding dedicated to the purchase of the battery ($327,000) and warranty ($55,000) was returned to the Denali Commission after the battery system failed to pass commissioning.

[xvii] Image from Premium Power literature advertising the Transflow 2000

[xviii] Dennis Witmer, "Factory Acceptance Test for the Transflow 2000 Battery at Premium Power, July 18-21, 2011," Energy Efficiency Evaluations, August 2011. http://energy-alaska.wdfiles.com/local--files/flow-battery-energy-storage-systems/Premium%20Power%20Factory%20Acceptance%20Test%20Report.pdf

[xix] A SCADA system controls and records data from different sensors in a system; these measurements can usually be seen in real time over large distances via the Internet.

[xx] PLCs are microcontrollers that can be programmed to interpret data received from digital and analog sensors, and can interact with different aspects of the system via switches, and motors.

[xxi] This is of particular significance to future Arctic installations. Traditional PVC hoses were replaced by Teflon due to higher thermal fluctuation tolerance. While more appropriate to the Arctic, this may add materials costs to units intended for Arctic climates.

[xxii] It should be noted that the project, targeting ARRA program funding, was originally intended to be one of several such demonstrations, and not the demonstration of a first-off unit.

[xxiii] The battery system should not only produce 500 kW, but per original specifications, do so for at least 2 hours on a sustained basis for a total energy output of between 1000- 2000 MWh. Regardless of specification, the need is for demonstration of significant and sustained energy and power production.

[xxiv] Efficiency will be calculated by measuring total ac energy in and total ac energy out, including all auxiliary loads such as pumps, cooling and processors required to operate the system.

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